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Point of care ultrasound and shock: The value in bedside diagnosis and hemodynamic assessment in undifferentiated shock patients

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ABSTRACT

Point of care ultrasound (POCUS) was introduced as a tool for critical care assessment in the 1990s and has since grown to be a tool for quantitative and qualitative data. Adopted initially by the emergency medicine community, it has recently been integrated into medical education for numerous specialties. It remains a valuable adjunct in the initial evaluation of patients as a widely available portable resource and provides real-time imaging. In patients who present in undifferentiated shock, visualization of the heart and lungs using POCUS can help delineate the cause of the clinical decompensation. Cardiac evaluation can look for right and left ventricular dysfunction, estimate left ventricle ejection fraction, evaluate for cardiac tamponade, and detect new wall motion abnormalities. Assessment of the lungs can add additional insight into underlying pathology. In patients who suffer cardiac arrest, POCUS can help identify any potentially reversible causes. It can also be used for hemodynamic assessment to aid in the resuscitation of patients with shock by evaluating of the inferior vena cava, hepatic, and renal veins. Here we provide a resource to describe not only the numerous benefits of POCUS in assessing and monitoring critically ill patients, but also the imaging findings of life-threatening diagnoses.

Key words: point of care ultrasound, shock, hemodynamic assessment, cardiac, pulmonary

INTRODUCTION

Point of care ultrasound (POCUS) is a portable diagnostic imaging tool to evaluate vital organ function as well as the absence or presence of pathology. Pioneered in the emergency and trauma settings, its use has slowly been integrated into intensive care units (ICU). In patients who are critically ill and in undifferentiated shock, POCUS can be used for rapid bedside assessment of life-threatening etiologies thus allowing for prompt intervention. POCUS is also useful for performing a hemodynamic assessment without the need for invasive devices, especially in unstable patients.[1] Here we provide a review of the utility and indications for which a patient can be evaluated using POCUS in the critical care setting.

Patients who present in shock are at risk for circulatory arrest from generalized tissue hypoxia resulting in multisystem organ failure. In the critical care space, real-time and accurate diagnosis is paramount in order to triage and adequately treat hemodynamically unstable patients. There are four categories of shock which are divided into distributive, cardiogenic, hypovolemic and obstructive shock [Figure 1]. Each form of shock has a unique pathophysiological process that ultimately results in clinical decompensation and management varies depending on the etiology. Despite this, patients can initially present similarly with hypotension, tachycardia, and altered mental status, which makes differentiating the type and cause of shock difficult. Early diagnosis with proper treatment of the corresponding shock has been shown to decrease mortality.[2] Diagnostic workup for identifying which type of shock a patient is in includes electrocardiogram (ECG), imaging, and lab work to evaluate organ function, tissue perfusion, and possible infections. These studies are paramount in helping to differentiate shock but can take time or require patients to be transported which may not necessarily be feasible in critical illness.

POCUS is a reliable and portable diagnostic tool that can be used at the patient's bedside to rapidly identify life-threatening conditions. POCUS slowly became incorporated in the critical care space into the 1990s with the focused assessment with sonography for trauma (FAST) exam to help uncover the presence of pathologic free fluid within the peritoneal cavity.[3] In time, the FAST exam soon replaced the diagnostic peritoneal lavage to identify blood within the abdominal cavity. In the 2000s, POCUS was used to help visualize structural landmarks while performing procedures and guiding interventional maneuvers or treatments that would have pre-

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Form	Etiology	Cardiac output	Systemic vascular resistance	Central venous pressure
Cardiogenic	Cardiomyopathy, STEMI, valvular disease, arrhythmia	↓	↑	↑
Distributive	Sepsis, anaphylaxis	↑	↓	↓
Hypovolemic	Hemorrhage	↑	↑	↓
Obstructive	Pulmonary Embolism Tamponade	↓	↑	↑

Figure 1. Different etiologies and physiologic findings seen in each form of shock. Up arrow: increase. Down arrow: decrease. STEMI, ST-elevation myocardial infarction.

viously been performed by palpation and anatomical knowledge. POCUS quickly became integrated as a diagnostic tool in the emergency room, where it could be used immediately on a decompensated patient for direct visualization of the heart and lungs.[4] In a prospective observational study with Veteran Affairs Institutions across the United States, cardiac (55%) and thoracic (56%) POCUS were utilized in patient care. Diagnostic evaluations using POCUS included left ventricular (LV) function and assessment for pericardial effusion and pleural effusions.[5]

POCUS is not only beneficial in rapidly decompensating patients but can also be used as a form of hemodynamic monitoring.[1] Hemodynamic monitoring is essential in the acute care setting to provide individualized patient care as well as to assess hemodynamics accurately. There are many clues to a patient's overall volume status at the bedside which are attained mainly by the means of a proper physical exam. One can examine the patient and assess mucous membranes, capillary refill, skin turgor, jugular venous pressure, central and peripheral edema and urine output to form a basic volume assessment. However, these physical exam findings may be difficult to assess in many patients and examination varies amongst providers.

Dynamic assessment of overall volume utilizes the Frank-Starling relationship, where an increase in volume in the under-resuscitated patient will lead to an increase in cardiac output and improve perfusion.[6] Non-invasive forms of hemodynamic monitoring include pulse pressure variation, end-expiratory occlusion test and passive leg raise.[7,8] While dynamic tests at the bedside are helpful in gauging overall fluid responsiveness, they can be inaccurate in severely hypovolemic patients or in those who are breathing spontaneously. More accurate forms of hemodynamic assessments include using a pulmonary artery catheter (PAC) or Swan-Ganz catheter.[9] In a prospective cohort study performed by Connor *et al.* including 5735 critically ill patients, patients with a PAC had an increased mortality and increased utilization of resources compared to patients without one.[10] While the PAC can be beneficial in assessing the hemodynamics of patients in cardiovascular shock, it is not applicable to all critically ill patients.

Ultrasound can provide a direct visualization of the inferior vena cava (IVC) to estimate the right atrial cardiac pressures. Additionally, hemodynamic measurements with POCUS include assessing for vascular congestion within the hepatic and renal veins. This is particularly helpful as physical exam findings can be less accurate in patients who are hemodynamically table.[11] When comparing physical exam findings to POCUS, up to 80% of patients who had no evidence of peripheral edema were found to have moderate to severe lung congestion on ultrasound.[12] In another study, 32% of patients who were initially thought to be euvolemic on a physical exam were ultimately found to be either hypovolemic or hypervolemic after an ultrasound examination of the IVC.[13] As such, POCUS can be used as a non-invasive tool to assess hemodynamic parameters including preload and potential fluid responsiveness.

Here we provide a review of how POCUS can be integrated within the critical care space through rapid assessment of life-threatening disease presentations to allow for prompt intervention and as a form of non-invasive hemodynamic assessment.

CARDIAC

Rapid assessment of cardiac function can be instrumental in developing a diagnosis in a critically ill patient. A focused cardiac POCUS allows for evaluation for pericardial effusion, biventricular size and function, aortic root diameter, and IVC.

LV assessment

In patients who are critically ill and rapidly decompensating, assessment of LV function is pertinent in evaluating hemodynamic instability. Bedside POCUS can assess LV systolic function, cardiac output, and potential wall motion abnormalities.

Estimating left ventricular ejection fraction (LVEF)

Initial attempts in evaluating overall LV function can be as rudimentary as observing the contractility of the ventricle. In rapid assessments of patients who are hemodynamically unstable, the ability to identify poor contractility of the LV, new cardiomyopathy, or thick or thin walls of the ventricle may be enough to consider a cardiac component for acute decompensation. However, visual assessment and estimation alone can be less accurate and can underestimate the function of the LV compared to quantitative assessments.[14]

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There are multiple quantitative ways that the LVEF can be calculated. The first method, which provides the best measurement of ejection fraction, is Simpson's Biplane Summation of Discs method.[15] This includes tracing the LV in both systole and diastole. Ejection fraction can be calculated as (Left Ventricular End Diastolic Volume [LVEDV] – Left Ventricular End Systolic Volume [LVESV])/LVEDV × 100.[15] While this is the most accurate way to measure the ejection fraction, it is the most time consuming and requires precision in tracing the LV, all of which may not be feasible on my handheld devices.

Another method used to estimate the LV function is calculating the mitral valve E point septal separation (EPSS).[16] EPSS can be measured in the parasternal long axis (PLAX) view with M-mode used over the distal tip of the anterior leaflet of the mitral valve [Figure 2].

In the tracing obtained by M-mode are two peaks: the "E-point", which represents the maximal opening of the mitral valve in early LV diastole, and the "A-point", which represents the atrial contraction during LV diastole.[16,17] A patient with a normal LVEF would have a small distance between the "E-point" and the septum, as the mitral valve should open with the leaflet almost hitting the septum. An EPSS greater than 7 mm is consistent with a reduced ejection fraction.[17] While EPSS is not as accurate as Simpson's method, it is a quicker way to estimate the overall ejection fraction.

Another way to assess ejection fraction is by using the fractional shortening method which gauges the fraction of the LV which shortens during the cardiac cycle [Figure 3]. In the parasternal short axis view, M-mode is used in the middle of the LV. The LV end-diastolic diameter and LV end-systolic diameter are measured and the ejection fraction can be calculated at (LV end diastolic diameter – LV end systolic diameter)/LV end diastolic diameter × 100.[18] The fractional shortening method can better estimate ejection fraction than EPSS, but can lead to overestimation or underestimation of the ejection fraction if wall motion abnormalities are present.

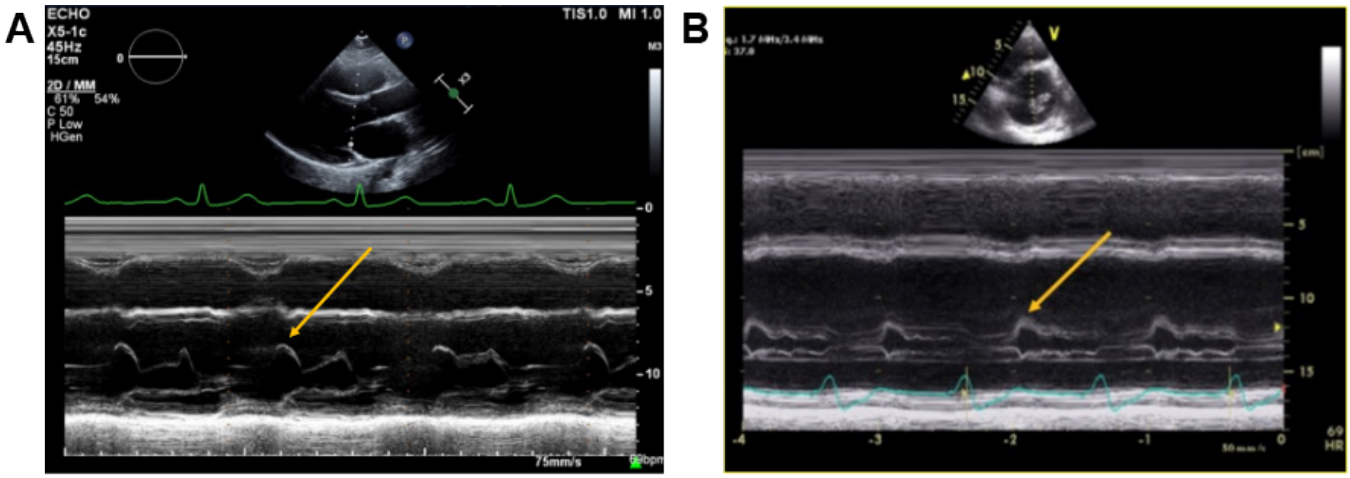

Figure 2. E-point septal separation. (A) EPSS (arrow) as an estimate of left ventricular function. M-mode is used over the anterior leaflet of the mitral valve in the PLAX. (B) EPSS in severely reduced LVEF. EPSS, E point septal separation; PLAX, parasternal long axis; LVEF, left ventricular ejection fraction.

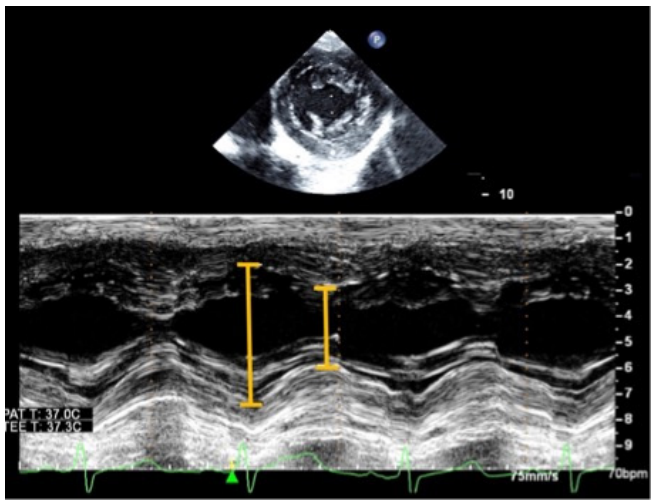

Figure 3. Assessment of left ventricular ejection fraction *via* fractional shortening. LV end systolic and diastolic diameter are measured using M-mode in the center of the of the left ventricle. Ejection fraction is calculated as ejection fraction can be calculated at (LV end diastolic diameter – LV end systolic diameter)/LV end diastolic diameter × 100. LV, left ventricular.

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Cardiac output

Cardiac output considers the patient's stroke volume and heart rate (HR) to assess the amount of blood that can be pumped from the heart each minute. A normal cardiac output is between 5-6 L/min. Invasive hemodynamic measurements of cardiac output include using a PAC and are calculated by either thermodilution or by Fick's principle. POCUS, on the other hand, can be used to calculate cardiac output without the need for invasive hemodynamic measurements. Stroke volume can be assessed by calculating the left ventricular outflow tract (LVOT) area and LVOT velocity time integral (VTI). The LVOT diameter, obtained by measuring between the aortic valve leaflet insertion points at mid systole in the PLAX, is used to calculate the LVOT area [Figure 4].[19] A typical LVOT diameter is approximately 2 cm.[19] Pulse wave doppler is used at the base of the aortic valve leaflets in the apical 5 chamber view.[19] The pulse wave signal can be measured to obtain the VTI [Figure 4]. Using this value, cardiac output is then calculated as ϖ (D/2)2 × LVOT VTI x HR.[19]

Wall motion abnormalities

When evaluating a patient who presents with chest pain, it is paramount to be able to differentiate between true acute coronary syndrome and other non-cardiac-related chest pain. POCUS is useful in providing additional information to supplement the patient's clinical presentation, ECG findings, and troponin levels. Bedside transthoracic echocardiogram (TTE) can help correlate a patient's ECG changes and corresponding coronary artery distribution to potential wall motion abnormalities. The LV walls can be assessed for akinesis, not moving at all, or hypokinetic, contracting less.

Cardiac tamponade

Cardiac tamponade occurs when there is a higher pressure within the pericardial space compared to the right atrium and ventricle. The lack of LV preload can result in a decrease in cardiac output. Clinically, the physical exam for cardiac tamponade is associated with Beck's triad, which is the combination of hypotension, jugular venous distention, and muffled heart sounds.[20] Pulsus paradoxus can also be observed through physical examination or *via* the waveform obtained from an arterial line.

In emergent situations with hemodynamically unstable patients, rapid assessment with POCUS can be lifesaving. On initial evaluation, POCUS can identify fluid in the pericardium [Figure 5]. TTE findings for impending tamponade physiology include right atrial systolic collapse.[21] As the pressure within the pericardium supersedes the right ventricle (RV), RV diastolic collapse can develop, which is specific for late cardiac tamponade.[21] RV diastolic collapse can be identified using M-mode through the parasternal view of the RV.[21] Lastly, given the increase in right sided pressures, the IVC would be found to be dilated.[21] While a dilated IVC can be seen in multiple pathologies, a collapsible IVC could rule out cardiac tamponade.

RV assessment

Declining right ventricular function contributes to both cardiovascular and pulmonary morbidity and mortality.[22] Compared to the LV, the RV has less musculature and as a result, cannot compensate for abrupt increases in pressure in the pulmonary arterial system. Rapid evaluation of the RV can address the possibility of right ventricular failure, pulmonary embolism (PE), pulmonary hypertension, and possible RV myocardial infarction. The right ventricular internal diameter should be less than two-thirds of the size of the LV. In cases where there is an elevation in the right ventricular pressure, the "D-Sign" can be seen in the parasternal short axis. The "D-Sign" describes interventricular septal flattening and deviation into the LV in the setting of right ventricular dysfunction. Instances in which the "D-Sign" can be present include PE, pulmonary hypertension, and right ventricular failure [Figure 6].[23]

The tricuspid annular plane systolic excursion (TAPSE) describes the displacement of the tricuspid annulus from the end of the diastole to the end of the systole. Measurement of the TAPSE requires using an M-mode with the ultrasound beam going through the lateral tricuspid valve annulus on the apical four-chamber view.[24] A TAPSE of 16 mm or less indicates right ventricular systolic dysfunction.

When there is clinical concern for PE, an assessment of the RV may be helpful. Right ventricular dilatation and hypo- or even akinesis of the mid-ventricular free wall with preserved motion of the apex can be seen. Known as McConnell's sign, it has historically been thought to be highly specific with poor sensitivity;

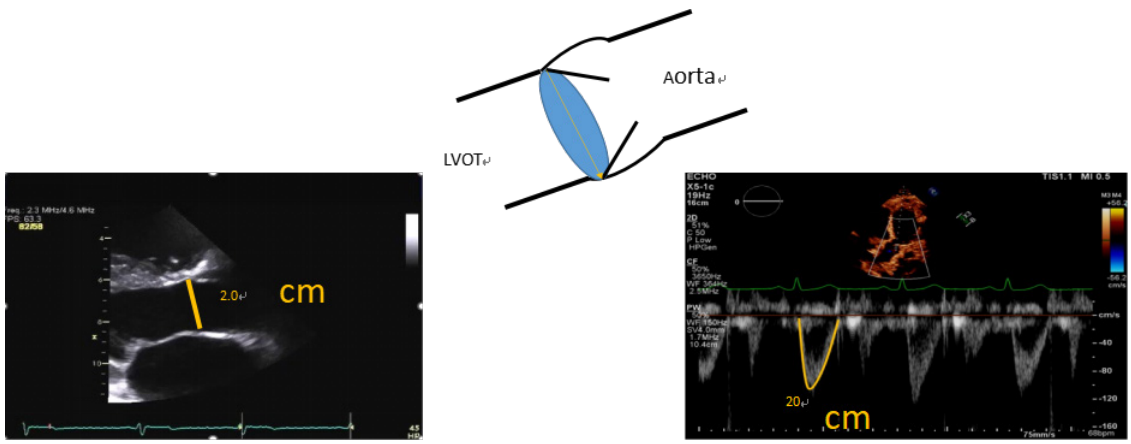

Figure 4. The LVOT diameter and VTI using pulse wave Doppler are measured to calculate the LVOT area and cardiac output. LVOT, left ventricular outflow tract; VTI, velocity time integral.

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however, even this is widely controversial.[25,26] As such, the utility of McConnell's sign is questionable, and should be discerned in each clinical context individually.

Valvular disease

The initial presentation in patients with severe valvular disease can be present with shortness of breath and hypotension, which is seen in patients with undifferentiated shock. Severe valvular disease can be an etiology leading to a patient's decompensated heart failure and possibly cardiogenic shock. Formal assessment of valvular disease with transesophageal echocardiography (TEE) includes multiple calculations and measurements. In acutely decompensated patients where there is little time for formal evaluation, utilizing POCUS can be beneficial for a bedside assessment. POCUS of the cardiac valve can identify if there is ruptured papillary muscle, flail leaflet or leaflet tethering.[27] Color flow doppler placed over the valves can help to identify the severity of valvular disease. Patients with severe valvular disease with normal atria and ventricles can indicate a rapid worsening of valvular disease without time for adequate remodeling.[27] Identification of patients with severe valvular disease early in patient presentation is paramount in determining whether patients need early surgical intervention.[28]

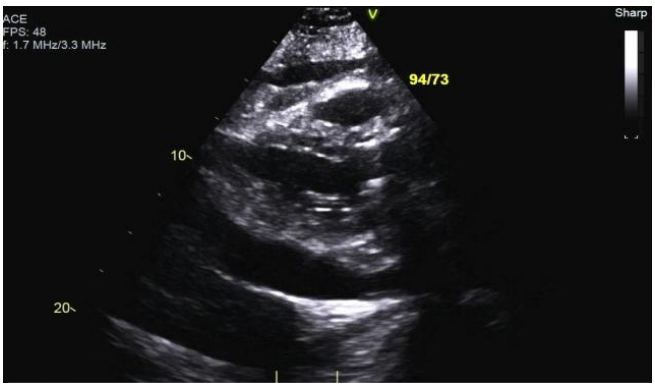

Figure 5. Pericardial effusion in a patient presenting with hypotension and tamponade.

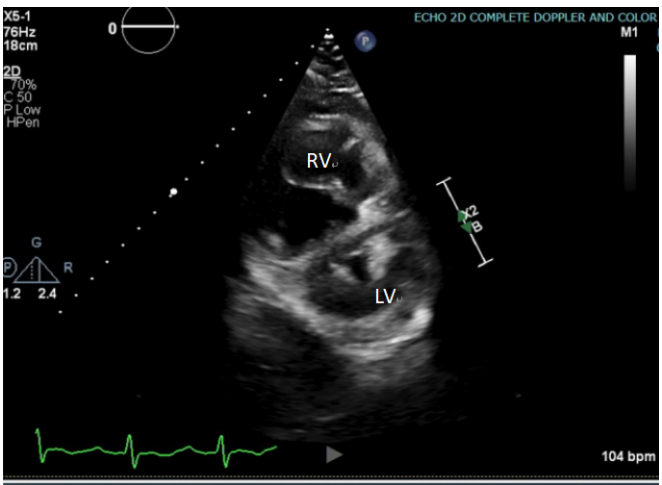

Figure 6. Right ventricular enlargement with increased pressures leading to "D"-shaped septum.

VASCULATURE

Aorta

The aorta can be divided into the thoracic aorta, which includes the ascending aorta and the aortic arch, and the descending aorta, which lies below the diaphragm. Ruptured aortic aneurysms and aortic dissections can be fatal if left untreated. While computed tomography (CT) angiography remains the gold standard in diagnosing an aortic dissection, in patients too unstable for CT scan, POCUS can be useful. In a thoracic aortic aneurysm, a dissection flap can be identified within the aorta creating a false lumen that moves with each contraction of the heart and can be visualized on the PLAX View [Figure 7].[29] Potential complications of aortic dissection include pericardial effusion, aortic root dilation, and/or aortic regurgitation which can be evaluated with the standard cardiac ultrasound windows.[29] Additionally, the suprasternal notch view allows for evaluation of the aortic arch, brachiocephalic artery, and left common carotid artery to determine if there is an aneurysm or dissection. The abdominal aorta can be easier to assess as compared to the thoracic aorta. Using the curvilinear probe, measurements of the abdominal aorta should be taken from the outer wall to the outer wall. An abdominal aortic aneurysm is defined as aortic diameter greater than 3 centimeters.[30] In a patient presenting with hypotension and abdominal pain and found to have an abdominal aortic aneurysm, this would warrant further imaging and workup for possible aortic dissection or rupture.

IVC

The IVC can be used as an estimate of right atrial pressure and overall volume status given that the IVC consists of two-thirds of systemic venous return.[31] On inspiration, the IVC diameter will decrease, leading to an increase in right ventricular pressure. The diameter of the IVC can be measured in the subcostal view. The "sniff test" used during IVC measurement identifies if the IVC is collapsible in response to decreased intrathoracic pressure and elevated intra-abdominal pressure with stark inhalation. An IVC diameter of less than 2.1 cm

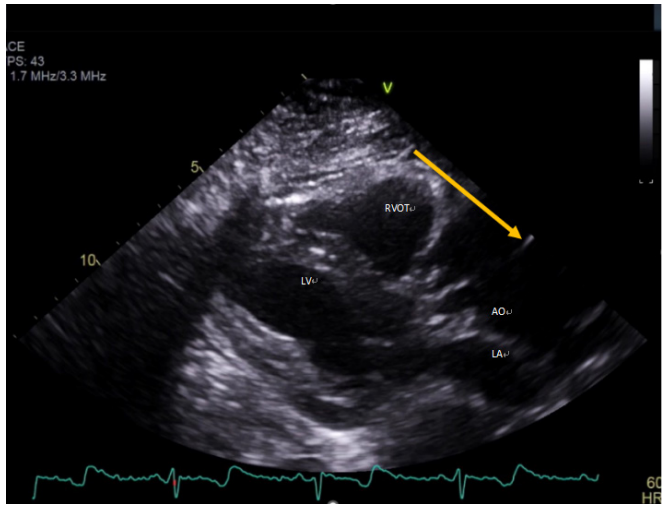

Figure 7. Aortic dissection flap (arrow) visualized using POCUS. POCUS, point of care ultrasound; RVOT, right ventricular outflow tract; LV, left ventricle; AO, aortic; LA, left atrium.

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with greater than 50% collapsibility suggests a central venous pressure (CVP) between 0-5 mmHg.[15] IVC diameter greater than 2.1 cm with less than a 50% collapse indicates a CVP between 10-20 mmHg.[15] Factors that can lead to an inaccurate measurement of the IVC include pulmonary hypertension, the presence of valvulopathies, or positive pressure ventilation.

For further assessment of overall fluid status, the Venous Excess Ultrasound (VExUS) protocol evaluates systemic vascular congestion using Doppler of the hepatic vein, portal vein, and intrarenal vein.[32] The IVC can first be measured and if the diameter is greater than 2 cm, Doppler should then be used to evaluate the hepatic vein at the juncture of the IVC.[32] Increased vascular congestion seen with Doppler ultrasound would show a diastolic wave larger than the systolic wave, which would be considered mild congestion.[32] A severe vascular congestion would have systolic wave flow blunting or reversal in the hepatic veins [Figure 8]. Lastly, the portal vein is examined with a pulse wave Doppler to measure variability.[32] The pulsatility index is equal to (Vmax – Vmin)/Vmax.[32] Severe pulsatility index would have a value greater than 50% and mild variability would be between 30%-49%.[32] A VExUS score of 0 is indicative of no congestion within the organ, while a VExUS score of 3 is considered to have severe congestion within 2 of the 3 organs.[33] While IVC evaluation can help in rapidly assessing volume status, VExUS is beneficial in identifying when to stop fluid resuscitation in a patient.[33]

Over-resuscitation can be equally as harmful as the under-resuscitation of a patient with shock. Excessive fluid administration results in an increase in both right and left atrial pressures manifesting as increased intravascular volume and then later extravascular volume due to leaky capillaries in the setting of global inflammation. This translates clinically to worsening pulmonary edema and renal congestion leading to hypoxia and respiratory distress, acute kidney injury, and/or hepatic congestion.[34]

LUNG EVALUATION

We will briefly touch upon lung ultrasound as an adjunct to cardiac POCUS however a more comprehensive review of lung POCUS will be described elsewhere.

Pleural effusion

Pleural effusion occurs with accumulation of fluid within the pleural cavity which can be unilateral or bilateral. It is best evaluated sonographically in the upright position while scanning the bilateral posterior chest wall and visualizing fluid within the pleural space. Ultrasound is more sensitive and specific than a two-view chest X-ray and can detect as little as 5 mL compared to about 50 mL by standard radiography.[35] In the ICU setting, fluid analysis provides clues to the type of shock whether it be septic, hemorrhagic, cardiogenic, *etc*. Pleural effusions often contribute to hypoxia, however, a particularly large collection of any cause can also displace mediastinal structures and obstruct cardiac return, contributing to tamponade-like physiology that resolves upon drainage with thoracentesis.[36]

Pulmonary edema

Acute hypoxic respiratory failure can be classified into either cardiogenic or noncardiogenic pulmonary edema such as Acute Respiratory Distress Syndrome (ARDS). To differentiate between the two, POCUS findings of a large pleural effusion (> 20 mm), decreased LV function and an IVC > 23 mm were predictive of cardiac pulmonary edema.[37] In the setting of progressive heart failure or cardiogenic shock, pulmonary capillary hydrostatic pressure increases. This causes fluid to leak into the lungs which manifests as B-lines on ultrasound. The more fluid leaks into the lungs, the denser the B-lines become. Patients with a low B-line ratio (the amount of B lines within the lung zones) were more likely to have a different etiology of their pulmonary edema, rather than a cardiac cause or ARDS.[37] Lung ultrasound was found to be both highly sensitive and specific in acute heart failure, boasting a higher sensitivity when compared to standard chest radiography.[38,39]

POCUS IN CARDIAC ARREST

A standardized approach in medicine can help reduce errors and improve the quality of care. The same applies to sonographic evaluation in an acutely, critically ill patient. As such, many protocols have been developed to help rapidly, effectively, and comprehensively assess for structural etiologies of a potentially reversible clinical decompensation. In this section, we will summarize a few protocols and discuss some of the challenges regarding POCUS in the setting of shock and cardiac arrest.

The rapid ultrasound for shock and hypotension (RUSH) exam was first described in 2006 and later published in 2008 by Weingart *et al.* In this protocol, which was one of the first of its

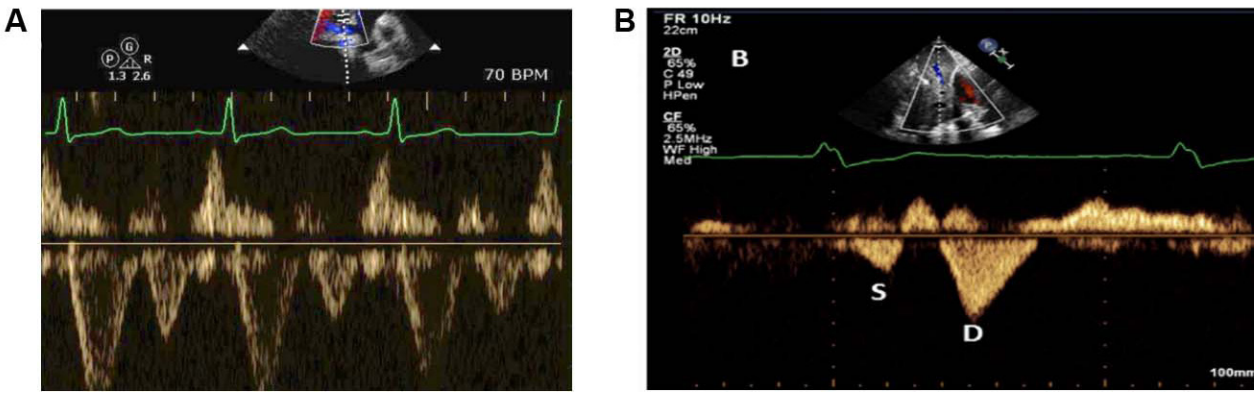

Figure 8. Hepatic Doppler flow patterns. (A) Normal hepatic Doppler flow pattern. (B) Blunted hepatic vein systolic flow(s) in a patient with congestion.

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kind, the mnemonic HI-MAP (Heart, IVC, Morrison's Pouch, Aorta, Pneumothorax) was used to help recall the components and sequence. The heart is scanned first utilizing the PLAX view and apical 4-chamber view to evaluate for cardiac tamponade and for right and LV size and function. The cardiac exam then concludes with the IVC for assessment of volume status. Next includes the search for abdominal free fluid at Morrison's pouch, the splenorenal recess, and the perivascular recess. The abdominal aorta is subsequently scanned for potential aneurysms or dissection. Finally, a pulmonary evaluation is performed to rule out tension pneumothorax. Requiring about 2-3 min for a comprehensive evaluation, a recent meta-analysis of the RUSH exam utilization concluded good diagnostic accuracy (81%) with high sensitivity (88%) and specificity (96%) in undifferentiated shock.[40]

Early protocols developed for ultrasound scanning during cardiopulmonary resuscitation (CPR) tended to solely focus on the heart.[41,42] Later protocols, however, expanded on this to take a more comprehensive approach to cardiac arrest. The first of these was the cardiac arrest ultrasound exam (CAUSE) which considers the most common and reversible causes of cardiac arrest not related to a primary ventricular arrhythmia.[43] It utilizes the subcostal view during compressions with other cardiac views and lung examination during the pulse check to rule out cardiac effusion and tamponade, massive PE, hypovolemia, and tension pneumothorax. The cardiac arrest sonographic assessment (CASA) was a further improvement upon this protocol calling for targeted evaluation of the heart during pulse checks with scanning of the lungs and abdomen occurring during compressions.[44] The timing of pulse checks was monitored by dedicated personnel to not exceed ten seconds. Supporting its utility, a small study showed that implementation of the CASA protocol was associated with a shorter duration pulse check during CPR as compared to the standard use of POCUS.[45] Other iterations of a regimented ultrasound evaluation during cardiac arrest have been developed since. These include the pulmonary, epigastric, abdominal (PEA) exam, the sequential echocardiographic scanning assessing mechanism (SESAME) protocol, and the sonography in hypotension and cardiac arrest (SHoC) protocol among others.[41,46,47] Evaluating the superiority of these protocols is difficult and may be meaningless due to a major concern that pulse checks are being prolonged for POCUS evaluation.[48] Current guidelines recommend that a pulse check last no greater than ten seconds.[49] While studies have shown that POCUS utilization during advanced cardiac life support (ACLS) significantly prolongs the duration of CPR interruption, educational interventions may provide a solution to this problem.[50]

A major limitation of surface echocardiography during ACLS is obtaining quality images and windows. Body habitus, body fluids expelled during cardiac arrest, limited time during pulse checks and other factors may impede in ability to obtain an interpretable image. As a result, focused TEE has been proposed to help bypass these limitations. This has particularly gained popularity in the emergency room setting. Intra-arrest TEE has both diagnostic and prognostic utility and can also monitor CPR quality.[51] In addition to this, TEE was shown to have shorter duration pulse checks as compared to transthoracic echocardiography.[52]

DISCUSSION

POCUS is a useful tool in being able to rapidly diagnose, resuscitate and treat a patient with undifferentiated shock. POCUS is of marked utility as it can be applied to the most unstable of patients who might not be able to tolerate invasive hemodynamic monitoring or further imaging. Another strength is that the ultrasound machine is portable and readily available as opposed to other types of imaging modalities. Furthermore, it has great diagnostic potential particularly as it pertains to cardiogenic, obstructive, distributive, or hypovolemic shock. With the ability to directly visualize intrathoracic and intraabdominal structures including the heart, lungs, and vessels, and to obtain extremely useful information by way of color Doppler and M-mode, the type of shock can be promptly delineated [Figure 9]. One study showed that the initial diagnosis was changed in 25% of patients after evaluation with POCUS.[53] Interestingly, 72% of examinations were performed in off-hours, meaning that it is a helpful tool when there is a lack of manpower or resources.[54] In a prospective controlled trial performed by Zieleskiewicz *et al.*, patients who experienced acute clinical decompensation in the ICU were placed in either a POCUS-guided management group versus a control group.[55] Patients in the POCUS-guided group had a focused assessment of the heart and lungs. These patients were found to have a faster time to treatment with a 93% diagnostic accuracy compared to the 78% in the control group.[55] In a different study, patients with early shock who were evaluated with POCUS for volume status were found to require less overall

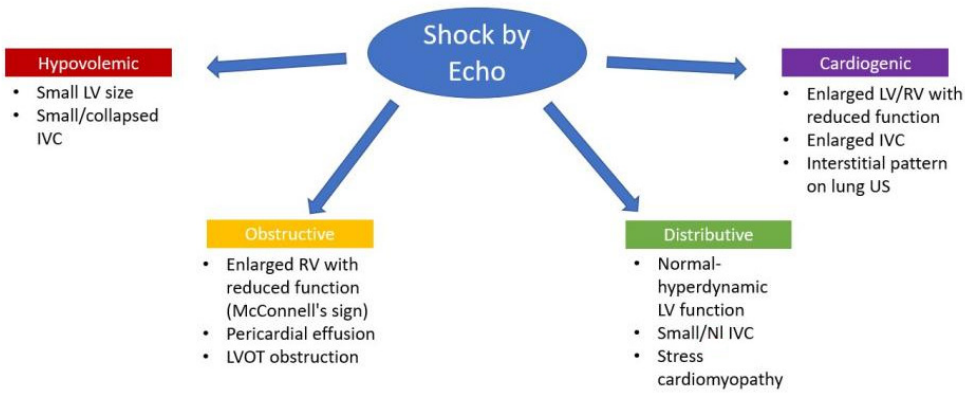

Figure 9. POCUS findings by shock physiology. LV, left ventricle; IVC, inferior vena cava; RV, right ventricle; LVOT, left ventricular outflow tract; US, ultrasound; POCUS, point of care ultrasound.

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time of vasopressor support and fewer days on mechanical ventilation and in the ICU in general.[56]

The role of POCUS has long been established as a multiorgan diagnostic tool, but it is being integrated as a tool for quantitative assessment of patients through hemodynamic monitoring. During active resuscitation of the patient in shock, POCUS provides live imaging of the left and RV and estimation of the CVP through IVC evaluation. For patients who are in cardiogenic shock, a PAC is an invasive tool to assess hemodynamics. An early echocardiogram with Doppler was able to identify patients in pre-shock versus early shock, which is beneficial as clinical symptoms of shock may at times present more indolently.[57] In patients examined with POCUS, 44% had a change in management and the IVC assessment in fluid status had the greatest influence in guiding management.[53]

Like all diagnostic tools, POCUS does have limitations in relation to patient care. The first is that scanning with ultrasound is user dependent. If a provider is less comfortable with scanning, there can be variability and even incorrect diagnoses. To combat this, the Society of POCUS has developed guidelines and core competencies for clinician training. Formal ultrasound programs are centered around these competencies and didactics include lectures, clinical rotations and integration in medical education from medical students to fellows. In 2007, ultrasound didactics became a requirement for all emergency medicine residencies throughout the United States. Repeated exposure and practice throughout graduate medical education allows time to master the skills and gain further exposure through training. Cleveland Clinic introduced a credentialing initiative for providers within their hospital system through standardization of ultrasound machines, a dedicated POCUS course, and administrative support.[58]

As the diagnostic modalities of POCUS continue to expand, there is still a lack of standardization for scanning. The RUSH, eFAST, and BLUE are only a few examples of the multiple different protocols that exist for scanning patients. While they each are valuable in evaluating pulmonary and cardiovascular functions, there is no standardized protocol that is adopted universally. A daunting task to regulate and identify a unifying POCUS protocol, the American Society of Echocardiography did release a guideline on recommendations for using POCUS with coronavirus disease 2019 (COVID-19) patients. The COVID-19 POCUS protocol included cardiac, lung, and fluid status with a recommended workflow to prevent excessive personnel exposure and conserve personal protective equipment. While it is still a daunting task to develop a standardized POCUS protocol, we do have an example to show that it is possible.

Like similar diagnostic imaging tools, POCUS only provides information about the patient at a fixed moment in time. As a result, POCUS should not replace gold standard recommendations for diagnosis. A prime example is in the setting of a PE. While right ventricular failure, D-sign and a dilated IVC would be suggestive of a PE, these findings can also be present in a patient with severe pulmonary hypertension. While POCUS is beneficial in helping to narrow a provider's differential, it should not replace a detailed history, thorough physical exam, and laboratory results. Similarly, limitations as they relate to the patient's positioning, body habitus or anatomy, can make obtaining an interpretable ultrasound image quite difficult. There should not be a delay in patient care and management to obtain POCUS images.

CONCLUSION

POCUS has revolutionized how clinicians diagnose, treat, and manage patients with life-threatening presentations. While POCUS was first used as a diagnostic tool that provided real time visualization of critical organs, it has also established a niche in hemodynamic monitoring. It is incredibly valuable in the setting of undifferentiated shock. The utility of POCUS will continue to grow throughout the medical specialties, and there will be a need for further standardization and guidelines for all providers. There is no doubt that POCUS is of vital importance for the efficacy and safety of delivering quality patient care.

Author contributions

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Informed consent

The authors declare that the images in the article were collected in their practicing and educating. All images are anonymous, de-identified cases without informed consent.

Conflict of interest

The authors declare no competing interest.

Data availability statement

No additional data.

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